

REMARKS

This paper is filed in response to the Office action mailed July 11, 2003, in which all of the claims of the application, namely claims 23-43 are rejected. With this paper no changes are made to the application, and so claims 23-43 are still pending.

Claim rejections under 35 USC §112, first paragraph

At paragraph 2 of the Office action, claims 23, 24, and 43 are again rejected under 35 USC §112, first paragraph, the Examiner asserting that, "if C is added to Si with a concentration at the [claimed] upper limit the lattice will change by more than the claimed amount and thus the claimed range is not enabled." In responding (at paragraph 22) to applicant's arguments regarding the 112 rejection--specifically, applicant's assertion that it is not possible to infer the strain and also that the strain and the C concentration are independent--the Examiner states that, "First, it is possible to infer the strain and Applicant is referred to Vegard's [sic] law. Second, whether the two are claimed as independent features or not, they are still bound together by the physics of the crystal."

It is the applicant's position that this argumentation of the Examiner is erroneous for the following reasons. Vegard's law is an approximate prediction of the lattice constant of a semiconductor alloy as a function of the concentration of the different constituents forming the alloy; it is based on the assumption that all atoms of the constituents of the alloy are on lattice sites. It therefore describes the physics of a crystal correctly only in the special situation of certainty about the substitutional concentration of all constituents. Therefore, if Vegard's law is to be applied to reliably predict

the lattice constant (and the strain) of a semiconductor alloy such as $\text{Si}_{1-y}\text{C}_y$ or $\text{Si}_{1-x-y}\text{Ge}_x\text{C}_y$, it is necessary to know the concentration of substitutional carbon in the lattice. However, the concentration of substitutional carbon in the lattice of the crystal recited in the rejected claims is not known. Thus, Vegard's law cannot exclude "by the physics of the crystal" that a carbon concentration of 10^{21} cm^{-3} , corresponding to the upper limit given in claim 23, necessarily induces a larger than 0.005 lattice change. Vegard's law does not work when the constituent concentration values used have an interstitial concentration component. Further, applicant emphasizes that claim 23 recites a total carbon concentration interval--i.e. substitutional plus interstitial--and recites limiting the substitutional carbon concentration so as to cause a change in the lattice of less than 5×10^{-3} (or in other words, to induce a relative lattice change of less than 0.005), i.e. what is claimed in claim 23 is providing carbon up to the upper limit of the recited range in such a way as to induce a relative lattice change of less than 0.005. (And so, e.g. providing carbon so as to cause a lattice change greater than 0.005 is not being claimed.)

Also in response to applicant's earlier arguments in respect to enablement, and specifically applicant's assertion that carbon can be interstitial and applicant's referring to Osten et al. in support thereof, the Examiner responds that,

... Lanzerotti et al. (IEEE) shows that in SiGeC the C is substitutional (p. 335, col. 1, line 3) and since the whole point of adding C is to reduce strain, it must be substitutional. Also note that Osten et al. refers to SiC.

Applicant respectfully submits that the Examiner is wrong in stating that Lanzerotti et al. (IEEE) "shows that in SiGeC

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the C is substitutional." The referred-to sentence includes the language,

assuming that all carbon atoms were substitutional on lattice sites and that one substitutional carbon atom compensates 8.3 germanium atoms. [Emphasis added.]

There is a clear difference between assuming that carbon is substitutional and showing that all carbon is substitutional. The fact that Lanzerotti et al. need to make an assumption at this point shows in fact that they did not assess the concentrations of substitutional and interstitial carbon and, in making their assumption, simply took a total carbon concentration value for the substitutional carbon concentration value. Thus, Lanzerotti et al. (IEEE) in fact do not show that all carbon is substitutional.

Applicant also respectfully objects to the Examiner stating that the whole point of adding carbon is to reduce strain and that carbon therefore must be substitutional. When adding carbon to a crystal in order to reduce the strain there must be enough substitutional carbon to achieve the desired effect. There can be no general exclusion of interstitial carbon incorporation into the Si or SiGe crystal. The existence of interstitial carbon in $\text{Si}_x\text{C}_{1-x}$ or SiGeC is a given fact, which the examiner should not neglect. See, Hoyt et al., *Thin Solid Films* 321 (1998), pp. 41-46, described below, which gives experimental proof for interstitial carbon in SiC and SiGeC. The actual point of the invention as claimed in claim 23 is to take into account the interstitial carbon. The invention does so by defining a strain limit for the given range of the total carbon concentration in the crystal.

Further, applicant respectfully objects to the Examiner stating that the reference to Osten et al. made in our last

response is not relevant since Osten et al. refers to SiC. First, please note that in the transistor claimed in claim 23 only the base layer contains SiGeC. The emitter and collector layers are made of silicon and may according to claims 23 contain carbon. Therefore, the Osten et al. reference is at least relevant for the incorporation of carbon into the emitter and collector layers. In addition, there is no substantial difference between the physics of incorporating carbon into Si and SiGe.

In further support of our argumentation that the concentration range given in claim 23 is the total carbon concentration, and that the strain limit recited in claim 23 in effect teaches a person to choose growth conditions that will lead to an appropriate concentration of substitutional carbon and a strain within the strain limit, we include the above-referenced paper of Hoyt et al., *Thin Solid Films* 321 (1998), pp. 41-46. This paper was published after the priority date of the present invention and is therefore not prior art. It shows that interstitial carbon is indeed a fact, stating at p. 41, left column, line 5:

Although a number of groups have investigated the maximum amount of carbon that can be incorporated in $\text{Si}_{1-x-y}\text{Ge}_x\text{C}_y$ by molecular beam epitaxy (MBE) and chemical vapor deposition (CVD), there has been less attention given to the fraction of the total carbon concentration that is substitutional on the lattice. For device applications, it is important to produce epitaxial layers with minimal non-substitutional carbon fractions.

Thus, Hoyt et al. shows that there is only a fraction of the total carbon concentration in $\text{Si}_{1-x-y}\text{Ge}_x\text{C}_y$ that is substitutional. The remaining carbon is "non-substitutional, i.e. it is interstitial carbon.

Further, in figure 2 of Hoyt et al., the substitutional carbon concentrations of different $\text{Si}_{1-x-y}\text{Ge}_x\text{C}_y$ samples are plotted versus the total carbon concentration. The substitutional carbon concentration is determined from the energy of X-ray peaks, such as those shown in figure 1. The total concentration is measured by secondary ion mass spectroscopy (SIMS). A diagonal dashed line in figure 2 shows what would be expected if the total carbon concentration was equal to the substitutional carbon concentration. This line therefore is indicative of the "ideal" case, which the examiner holds as the only possible case, in which all carbon incorporated is substitutional. The experimental points taken under different experimental conditions show that the substitutional carbon concentration is below the diagonal line for total carbon concentrations higher than about 1.0 atomic %, i. e., about $6 \times 10^{20} \text{ cm}^{-3}$. This result obtained for SiGeC confirms that in general not all carbon is incorporated substitutionally. Looking at the results for SiC in the same figure, the fraction of substitutional carbon is even lower than for SiGeC. This experimental result shows that carbon can indeed be incorporated at the upper concentration limit of 10^{21} cm^{-3} recited in claim 23 while causing strain below the limit of 0.005.

Further still, figure 5 of Hoyt et al. shows that by choosing an appropriate growth temperature and precursor for carbon the substitutional carbon fraction can be controlled. This example for SiC supports our argumentation that it is simply a matter of choosing appropriate growth conditions by which the person skilled in the art is able to control the fraction of substitutional carbon incorporated in the lattice, given a total carbon concentration. For example, according to Figure 5, given a total carbon concentration of 1.2 atomic %,

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the substitutional carbon concentration can be changed from 0.3 atomic % to 1.2 atomic % by lowering growth temperature from 700 °C to 550 °C. Therefore, since only substitutional carbon changes the lattice constant, Hoyt et al. show that the strain in a $\text{Si}_{1-y}\text{C}_y$ or $\text{Si}_{1-x-y}\text{Ge}_x\text{C}_y$ layer can be controlled by choosing appropriate growth conditions.

Finally, as is known, the strain level at a given substitutional carbon concentration also depends on the Germanium concentration. The strain components of Ge and C compensate each other. For a Ge concentration of 30 %, the substitutional C concentration must be about 2 % (i.e., about $1 \times 10^{21} \text{ cm}^{-3}$) to achieve the strain limit of claim 23. Therefore, the parameters recited in claim 23 can be realized for some Ge concentrations even if all carbon is incorporated on lattice sites.

Applicant therefore respectfully submits that the addition of C even at the upper limit of the claimed range will not necessarily cause of change in the strain/ lattice (constant) of more than one half percent.

Further, applicant respectfully submits an affidavit under Rule 32 asserting same, and furthermore stating that a transistor has in fact been fabricated so as to have in at least one layer carbon in a concentration of as much as 10^{21} atoms per cm^3 , and having a change in the lattice of less than one half percent.

Applicant thus respectfully requests that the rejections of claims 23, 24, and 43 under 353 USC §112, first paragraph, be reconsidered and withdrawn.

Claim rejections under 35 USC §103

At paragraph 4 of the Office action, claims 23-25, 29-34, 40 and 41 are rejected under 35 USC §103 as being unpatentable over Lanzerotti et al., *Si/Si_{1-x-y}Ge_xC_y/Si Heterojunction Bipolar Transistors*, IEEE, hereinafter IEEE, in view of Lanzerotti et al, *Suppression of Boron Outdiffusion in SiGe HBTs by Carbon Incorporation*, IEDM, hereinafter IEDM.

Claims 29-34 and 40-41 all depend from claim 25, which is independent. Claims 23 and 24 are each independent.

With respect to claims 23 and 24, applicant respectfully submits that it is not fair of the Examiner to assert on the one hand that the invention as recited is not possible according to the laws of physics, and then to assert on the other hand that the invention is obvious.

Further with respect to claims 23 and 24, IEEE teaches a nominal 1.1% C concentration in the Si_{0.739}Ge_{0.25}C_{0.011} base and the adjacent spacer layers (p.334, lines 7 to 9). The strain in these layers can be determined using the results of a paper by H.J. Osten in *Materials Science and Engineering B36* (1996), pp. 268-274 (copy enclosed). Fig. 2 at p. 270 of the paper shows the dependency of the misfit (right scale) on the C concentration in the lattice for several given Ge concentrations (left scale), calculated according to Eq. (1) on p. 270, left column. According to this, as is well known, the misfit decreases with increasing C concentration to reach zero at a certain C concentration. The slope of the decrease of the misfit is the same for all Ge concentrations. Thus, for the material of IEEE, by graphical interpolation using a parallel line for the dependency at 25% Ge, a value of the misfit of about 0.6% (i.e. 6×10^{-3}) is obtained. This value is 20%

higher, and therefore clearly above the maximum value of 5×10^{-3} recited in claim 23, from which all of the rejected claims depend. IEDM has a nominal 0.5% C concentration in the $\text{Si}_{0.795}\text{Ge}_{0.2}\text{C}_{0.005}$ base and the adjacent spacer layers (Fig. 1b, c). Using the same method of strain determination, a value of 6×10^{-3} is obtained also for this material. This result is plausible because in comparison with the material of IEED, the lower value of the misfit introduced by a lower Ge concentration is only compensated for to a smaller extent by the lower C concentration of 0.5%. Thus, no combination of IEED and IEDM can provide the transistor recited in claims 23 and 24.

Now with respect to claims 25 and 29, according to the Examiner, the removal of spacer layers is obvious from IEDM because it shows "it is necessary to reduce the base resistance," and because removing the undoped spacer layers would have that effect, which implies that they should be removed. Applicant respectfully submits that this argumentation of the Examiner misreads IEDM. First, IEDM does not teach that it is necessary to reduce the base resistance, as the Examiner asserts, but instead that it is important to have a low base sheet resistance (p.249, Introduction, first paragraph). The base sheet resistance is a resistance per unit area. The base sheet resistance according to IEDM is reduced by increasing the boron concentration (p.249, Introduction, first paragraph). However, the base sheet resistance cannot be changed by omitting a layer, not even by making a layer thinner. Therefore, omitting undoped spacer layers is not implied or suggested by IEDM.

Furthermore, IEDM teaches away from omitting spacer layers. It shows (at p.249, second paragraph under Introduction) that heavily doped base layers cause boron out-diffusion from the base, which impairs transistor performance. IEDM further teaches

(in the third paragraph of the Introduction) that "to accommodate the outdiffusion of boron ..., undoped spacer layers of SiGe are usually grown on either side of the doped bases." These spacer layers, according to IEDM, have the problem that they can only be grown with a certain thickness since they have a finite critical thickness before dislocation formation. Therefore, the problem faced by IEDM was that on one hand dislocation formation in spacer layers must be avoided, but on the other hand dislocation-free (i.e. rather thin) spacer layers cannot sufficiently prevent out-diffusion of boron from a highly boron-doped base layer into the emitter and collector layers. The solution to this problem provided by IEDM is to include carbon in the base layer. This way, boron out-diffusion is limited, and, according to the teaching of IEDM, spacer layers can be grown free of dislocations with a thickness according to the previous art.

This teaching is expressed implicitly in the structure of the transistors disclosed in IEDM, which all contain 100 or 50 undoped spacer layers (p. 249, right column, first and last paragraph). There is no mention of omitting the spacer layers. In fact, different samples described in IEDM all contain 100 or 50 undoped spacer layers on either side of the base layer "to accommodate any boron diffusion during the emitter growth" (see p. 249, right column, lines 3-7). Furthermore, IEDM explicitly shows that the sample transistors having 50 spacers exhibit poor figures of merit, implying that reducing the thickness even further would further impair transistor performance; see p. 249, right column, last two sentences, and p. 250, first paragraph, which reads:

Applying a 1 V reverse bias to the collector of the 50 spacer devices increases J_{co} by a factor 2.2, but does not affect the J_{co} of the 100 spacer devices.

This increase in collector current with increasing base-collector reverse bias is reflected in the common-emitter characteristics by the drop in Early voltage from ~50 V for the 100 spacer transistors to ~0.5 V for the 50 spacer transistors. One may conclude that the B profile is not sufficiently abrupt on a 50 scale in the as grown wafers. [Emphasis added]

Thus, a 50 spacer is not thick enough to provide a sufficiently abrupt boron doping profile. Omitting the spacers would therefore lead to an even less abrupt doping profile.

In summary, whereas the present invention recites in claim 25 a transistor structure without spacer layers, IEDM teaches away from a transistor as in claim 25, since IEDM teaches including spacer layers of no less than 100 on either side of the base layers to achieve a boron doping profile abrupt enough to avoid out-diffusion into the emitter and collector layers.

For the foregoing reasons, applicant respectfully requests that the rejection under 35 USC §103 of claims 23-25 and 29 be reconsidered and withdrawn.

With respect to claims 30-34 and 40 and 41, these claims all depend from claim 25 and so are believed allowable for the reasons given above in respect to claim 25. Therefore, applicant respectfully requests that the rejections under 35 USC §103 of claims 30-34 and 40 and 41 also be reconsidered and withdrawn.

At paragraphs 12, 15, 17 and 19 of the Office action, claims 26-28, 35-39, and 42 are rejected under 35 USC §103 as being unpatentable over IEEE in view of IEDM and further in view of other references. To the extent that the Examiner has not responded to arguments made in response to the previous Office action, applicant renews such arguments. Further, each of claims 26-28, 35-39, and 42 depends from claim 25, which is believed patentable for the reasons given above. Accordingly, applicant

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respectfully requests that the rejections under 35 USC §103 of claims 26-28, 35-39, and 42 be reconsidered and withdrawn.

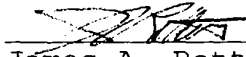
Conclusion

For all the foregoing reasons it is believed that claims 23-43 are in condition for allowance and their passage to issue is earnestly solicited. Applicant's attorney urges the Examiner to call to discuss the present response if anything in the present response is unclear or unpersuasive.

Respectfully submitted,

Dated: November 11, 2003

WARE, FRESSOLA, VAN DER
SLUYS & ADOLPHSON LLP
Bradford Green, Building Five
755 Main Street, P.O. Box 224
Monroe, CT 06468
Telephone (203) 261-1234
Facsimile (203) 261-5676
USPTO Customer No. 004955


James A. Retter
Attorney for the Applicant
Registration No. 41,266